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Team 2: Using Data Farming to Examine Various Aspects of the Transformable Craft

Balestrini-Robinson, Santiago

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TEAM 2 MEMBERS

Dr. Santiago Balestrini-Robinson
Georgia Institute of Technology

Mr. Paul T. Beery
Naval Postgraduate School, US

Maj. Huntley Bodden
Naval Postgraduate School, US

LT Robert Cizek
Naval Postgraduate School, US

LT Herb Hernandez
Naval Postgraduate School, US

MAJ Sebastian Scheibe
German Army

INTRODUCTION

In 2005 the Office of Naval Research (ONR) released Broad Agency Announcement (BAA) 05-020 detailing the desired capabilities for the Transformable Craft (T-Craft). The T-Craft will provide a “game changing” capability for the US Navy’s sea basing concept. T-Craft will advance the concepts of operational maneuver from the sea (OMFTS) and ship-to-objective maneuver (STOM). The T-Craft will improve the current US Navy capabilities by improving the cargo limitations of the Landing Craft Air Cushion (LCAC) and the speed limitations of the Landing Craft Unit (LCU).

The pertinent T-Craft capabilities modeled are:

1. Un-refueled range, in a no cargo condition, of 2,500 nautical miles (20 knots)
2. Full load condition speed of 40 knots
3. Amphibious capability to traverse sand bars and mud flats providing “feet dry on the beach”
4. Un-refueled range in high speed of 500-600 nautical miles (40 knots)

BAA 05-020 details the full list of desired capabilities of the T-Craft. This IDFW 20 study was conducted to examine those capabilities, while focusing on the following areas:

1. Determine critical factors and their threshold values and sensitivities.
2. Model T-Craft behavior and survivability in a hostile environment.

MODEL 1

Robust Analysis of Desired Capabilities of the Transformable Craft in Seabasing Missions

Model Description

The first model was created in Arena to simulate the transportation of troops to shore aboard T-Craft. Figure 1 provides an overview of the model. The T-Crafts loads troops at the sea base, transits to the shore, converts to Air Cushion Vehicle (ACV) mode, offloads the troops at the shore, converts back to Surface Effect Ship (SES) mode and transits back to the sea base. If necessary the T-Crafts are refueled and loaded again until all troops are projected to shore. During transit and unloading the T-Crafts may suffer from enemy hits and sink. These hits reduce the amount of troops that reach the shore and causes T-Craft loses.

Design of Experiments

Table 1 presents the input parameters used in the model. Decision factors are directly related to the desired capabilities of the T-Craft. Noise factors consider operational dependencies.

The experiment utilized a Nearly Orthogonal Latin Hypercube (NOLH) design with 29 factors and 28 rotations for all non-binary variables and a Hamardard matrix for the two binary variables (11 and 31) were crossed. The results of

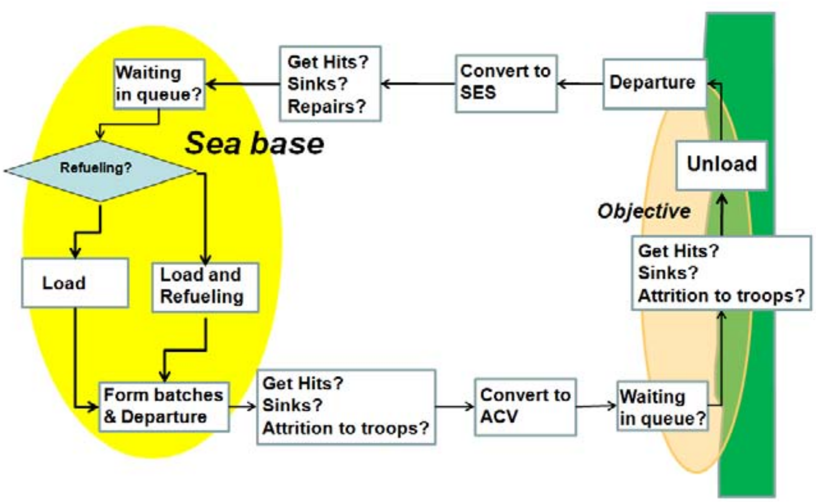


Figure 1: Generic Model Overview of the Arena Model

the crossing is 29,700 runs. For every run 4 replications were done. This effort resulted in a final total of 118,800 runs. Effectiveness was evaluated with three different Measures of Effectiveness (MOEs): the time to complete a mission (hours), the Cargo Onshore Rate, and the T-Craft Destroyed Rate.

S/N	Factor	MIN VALUE	MAX VALUE	
1	Cargo Payload Weight (LT)	300	1000	
2	Cargo Deck Size (sqft)	2200	10000	
3	Speed SES (knts)	35	55	
4	Speed ACV (knts)	4	10	
5	Load Time (hrs)	1	5	
6	Unload Time (hrs)	1	4	
7	Time to Convert to ACV (hrs)	0.25	1	
8	Time to Convert to SES (hrs)	0.25	1	
9	# T-Crafts	6	22	Decision Factors
10	# SeaSpots	5	13	
11	Refueling during loading? (1-yes, 0-no)	0	1	
12	Refueling rate (tons/hour)	80	160	
13	Tank capacity (LT)	110	150	
14	Batchsize	1	22	
15	ProbFailure	0.01	0.1	
16	Time to repair (hrs)	1	3	
17	# hits to repair	1	5	
18	Total Load (LT)	5000	40000	
19	Footprint MEB (sqft)	50000	120000	
20	Deck Use Efficiency (between 0 and 1)	0.7	0.95	
21	Distance (nm)	25	250	
22	TransitionDistance (nm)	0.5	5	
23	# ShoreSpots	3	22	
24	ProbHit Batch (%)	0.01	0.5	Noise Factors
25	ProbHit Batch during Unloading (per hour)	0.01	0.5	
26	AttritionRate Troops	0.01	0.5	
27	ProbSink (1 Hit)	0.01	0.3	
28	ProbSink (2 Hits)	0.31	0.5	
29	ProbSink (3 Hits)	0.51	0.75	
30	ProbSink (4 Hits)	0.76	0.99	
31	Distribution (0-TRIA, 1-ShiftedEXPO)	0	1	

Table 1: Decision Factors and Noise Factors

Data Analysis

Data was summarized by averaging over the noise factor space. A model was then fitted by including two-way-interactions and quadratic effects. Figure 2 shows the distribution of the MOEs.

Figures 3, 4, and 5 show the fitted model parameters for the individual MOEs and the Prediction profilers.

Figure 3 shows that the # T-Crafts, Load Time, Cargo Payload Weight, Batch Size, and Unload Time are the most significant factors affecting the mean of Time to Complete.

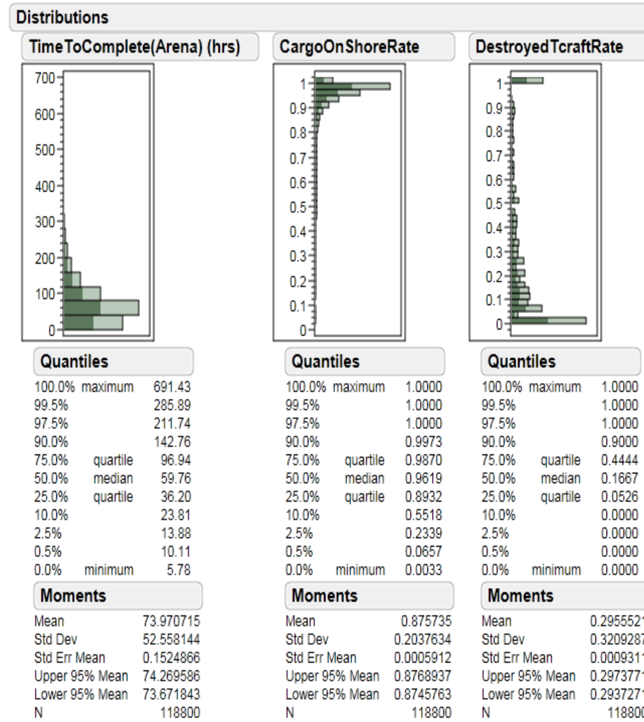


Figure 2: Distribution of the Time to Complete, Cargo Onshore Rate, and destroyed T-Craft Rate

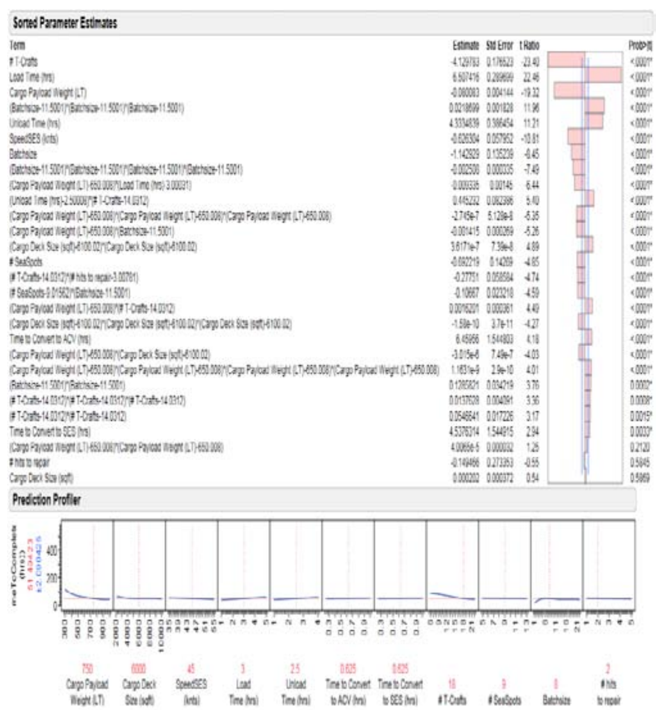
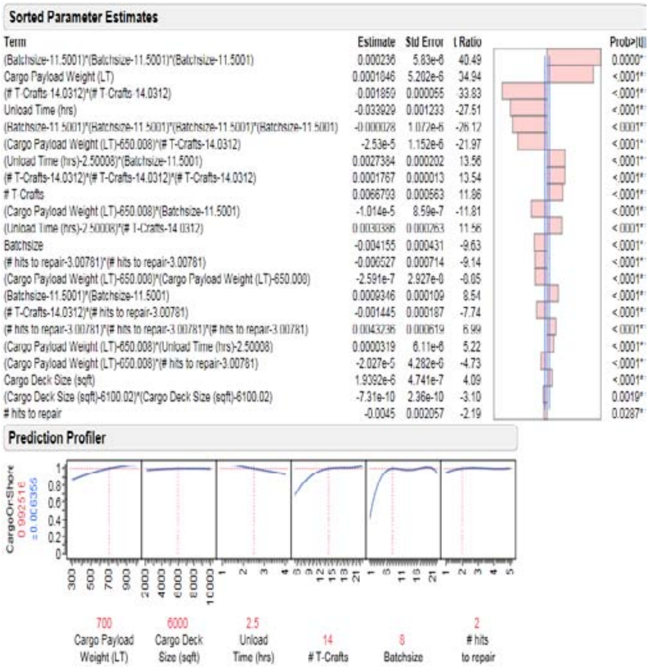


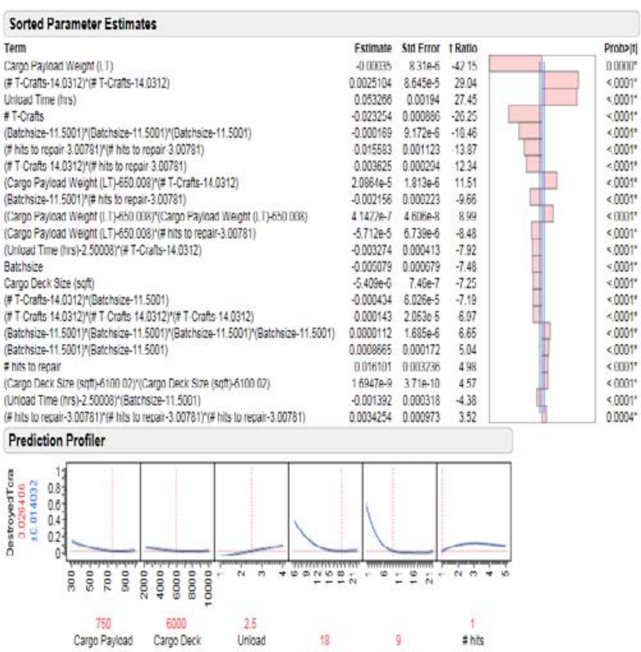
Figure 3: Sorted Parameter Estimates and Prediction Profiler of the Mean (Time To Complete) for the decision factors



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
(Batchsize-11.5001)*(Batchsize-11.5001)*(Batchsize-11.5001)	0.000236	5.83e-6	40.49	0.0000*
Cargo Payload Weight (LT)	0.0001846	5.202e-6	34.94	<.0001*
(# T-Crafts-14.0312)*(# T-Crafts-14.0312)	0.001859	0.000055	33.83	<.0001*
Unload Time (hrs)	-0.033929	0.001233	-27.51	<.0001*
(Batchsize-11.5001)*(Batchsize-11.5001)*(Batchsize-11.5001)*(Batchsize-11.5001)	-0.000028	1.072e-6	-26.12	<.0001*
(Cargo Payload Weight (LT)-650.008)*(# T-Crafts-14.0312)	-2.53e-5	1.152e-6	-21.97	<.0001*
(Unload Time (hrs)-2.50008)*(Batchsize-11.5001)	0.0027384	0.000202	13.56	<.0001*
(# T-Crafts-14.0312)*(# T-Crafts-14.0312)*(# T-Crafts-14.0312)	0.0001767	0.000013	13.54	<.0001*
# T-Crafts	0.0066793	0.000563	11.86	<.0001*
(Cargo Payload Weight (LT)-650.008)*(Batchsize-11.5001)	-1.014e-5	8.59e-7	-11.81	<.0001*
(Unload Time (hrs)-2.50008)*(# T-Crafts-14.0312)	0.0030386	0.000263	11.56	<.0001*
Batchsize	-0.004155	0.000431	-9.63	<.0001*
(# hits to repair-3.00781)*(# hits to repair-3.00781)	-0.006527	0.000714	-9.14	<.0001*
(Cargo Payload Weight (LT)-650.008)*(Cargo Payload Weight (LT)-650.008)	-2.591e-7	2.927e-8	-8.85	<.0001*
(Batchsize-11.5001)*(Batchsize-11.5001)	0.0009346	0.000109	8.54	<.0001*
(# T-Crafts-14.0312)*(# hits to repair-3.00781)	-0.001445	0.000187	-7.74	<.0001*
(# hits to repair-3.00781)*(# hits to repair-3.00781)*(# hits to repair-3.00781)	0.0043236	0.000619	6.99	<.0001*
(Cargo Payload Weight (LT)-650.008)*(Unload Time (hrs)-2.50008)	0.0000319	6.11e-6	5.22	<.0001*
(Cargo Payload Weight (LT)-650.008)*(# hits to repair-3.00781)	-2.027e-5	4.282e-6	-4.73	<.0001*
Cargo Deck Size (sqft)	1.9392e-6	4.741e-7	4.09	<.0001*
(Cargo Deck Size (sqft)-6100.02)*(Cargo Deck Size (sqft)-6100.02)	-7.31e-10	2.36e-10	-3.10	0.0019*
# hits to repair	-0.0045	0.002057	-2.19	0.0287*

Figure 4: Sorted Parameter Estimates and Prediction Profiler of the Mean (Cargo Onshore Rate) for the decision factors



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Cargo Payload Weight (LT)	-0.00035	8.31e-6	-42.15	0.0000*
(# T-Crafts-14.0312)*(# T-Crafts-14.0312)	0.0025104	8.645e-5	29.04	<.0001*
Unload Time (hrs)	0.053266	0.00194	27.45	<.0001*
# T-Crafts	-0.023254	0.000886	-26.25	<.0001*
(Batchsize-11.5001)*(Batchsize-11.5001)*(Batchsize-11.5001)	-0.000169	9.172e-6	-18.46	<.0001*
(# hits to repair-3.00781)*(# hits to repair-3.00781)	-0.015583	0.001123	-13.87	<.0001*
(# T-Crafts-14.0312)*(# hits to repair-3.00781)	-0.003625	0.000294	-12.34	<.0001*
(Cargo Payload Weight (LT)-650.008)*(# T-Crafts-14.0312)	2.0864e-5	1.813e-6	11.51	<.0001*
(Batchsize-11.5001)*(# hits to repair-3.00781)	-0.002156	0.000223	-9.66	<.0001*
(Cargo Payload Weight (LT)-650.008)*(Cargo Payload Weight (LT)-650.008)	4.1472e-7	4.606e-8	8.99	<.0001*
(Cargo Payload Weight (LT)-650.008)*(# hits to repair-3.00781)	-5.712e-5	6.739e-6	-8.48	<.0001*
(Unload Time (hrs)-2.50008)*(# T-Crafts-14.0312)	-0.003274	0.000413	-7.92	<.0001*
Batchsize	-0.005079	0.000679	-7.48	<.0001*
Cargo Deck Size (sqft)	-5.409e-6	7.46e-7	-7.25	<.0001*
(# T-Crafts-14.0312)*(Batchsize-11.5001)	-0.000434	6.026e-5	-7.19	<.0001*
(# T-Crafts-14.0312)*(# T-Crafts-14.0312)*(# T-Crafts-14.0312)	-0.000143	2.053e-5	-6.97	<.0001*
(Batchsize-11.5001)*(Batchsize-11.5001)*(Batchsize-11.5001)*(Batchsize-11.5001)	0.0000112	1.685e-6	6.65	<.0001*
(Batchsize-11.5001)*(Batchsize-11.5001)	0.0008665	0.000172	5.04	<.0001*
# hits to repair	0.016101	0.003236	4.98	<.0001*
(Cargo Deck Size (sqft)-6100.02)*(Cargo Deck Size (sqft)-6100.02)	1.6947e-9	3.71e-10	4.57	<.0001*
(Unload Time (hrs)-2.50008)*(Batchsize-11.5001)	-0.001392	0.000318	-4.38	<.0001*
(# hits to repair-3.00781)*(# hits to repair-3.00781)*(# hits to repair-3.00781)	0.0034254	0.000973	3.52	0.0004*

Figure 5: Sorted Parameter Estimates and Prediction Profiler of the Mean (Destroyed T-Craft Rate) for the decision factors

Figure 4 shows that Batch Size, Cargo Payload Weight, # T-Crafts, Unload Time, and Number of Hits to Repair are the most significant factors affecting the mean of Cargo Onshore Rate.

Figure 5 shows that Cargo Payload Weight, # T-Crafts, Unload Time, and Batch Size are the most significant factors affecting the mean of T-Craft Destroyed Rate.

It should also be noted that further analysis demonstrated RSquare values between 0.351 and 0.546.

Fitting partition trees on the means of the three MOEs also gave # T-Craft, Batch Size, and Cargo Payload Weight as the most significant factors.

MODEL 1 CONCLUSIONS

The most significant factors across all MOEs were: # T-Craft, Batch Size, Cargo Payload Weight, Unload Time, Load Time and Number of Hits to Repair. In order to decrease the mean Time to Completion, the number of T-Crafts should be increased. Cargo Payload Weight can also be increased. It is recommended that the number of T-Craft be maximized (within budget) and the Cargo Payload Weight should be as large as possible. The robust analysis gave us also some interesting threshold values: In order to achieve the shortest mission durations, the number of T-Craft should be at least 18 and the Cargo Payload Weight should exceed 750 LT. To get a high Cargo Onshore rate and a low destroyed T-Craft Rate, the batch size should exceed 9 and the survivability of the T-Crafts should allow two hits before major repairs are needed. Also, Load time and Unload Time should be as small as possible, and the Deck size area of the T-Craft should exceed the objective of 5500 sqft.

MODEL 2

Developing and Data Farming a Mission Model of the Transformable Craft in an Operational Environment

A second model was developed to address two major questions:

1. Does the T-Craft need an organic self-defense capability?
2. How should the T-Craft be employed when a threat exists?

The above questions were addressed with an agent based simulation tool developed by the New Zealand defense forces called Map Aware Non-uniform Automata (MANA). MANA was utilized to explore two scenarios, a peace keeping/peace enforcement operation in Columbia and a regional conflict in Malaysia. The scenarios were based on a threat assessment within the regions. The models assume that the sea base consists of two amphibious ready groups (ARG), section of T-Craft, LCS surface and anti-surface packages, and MPF(F).

Design of Experiments

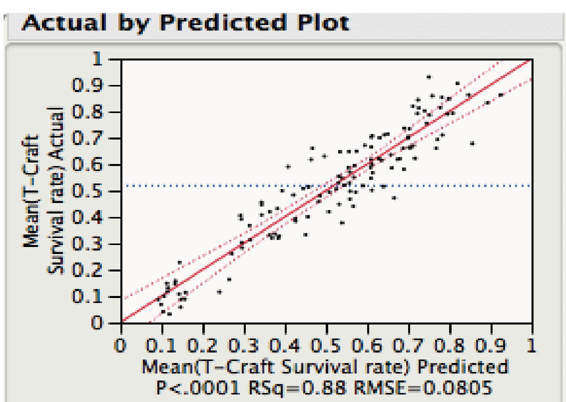
The initial DOE was focused on gleaning insight on how T-Craft survivability is affected in four different cases: armed, not armed, armed and escorted, and not armed and escorted. The design consisted of a NOLH with 8 factors and 125 design points. Each design was run 50 times. The measure of effectiveness in the experiment is the mean T-Craft survival rate. The factors are their levels are summarized in Table 2.

Factor Name	Range
Number T-Craft	5 – 11
T-Craft Armed	1 – 0 (Yes – No)
T-Craft Escort	1 – 0 (Yes – No)
Alt Waypoint (back to Sea Base)	1 – 0 (Yes – No)
Speed	35 – 55
Number Red Patrol Boats	5 – 10
Number Red Semi-submersibles (scenario I)	5 – 10
Number Red SWARM boats (scenario 2)	5 – 10

Table 2: Factors and Ranges

Data Analysis

After the initial runs with both models, escorting and arming the T-Craft appeared to have increased survivability. The results were obtained through regression analysis, partition plots, and analysis of the distribution. The regression analysis and partition plot results for the first scenario (Columbia) are presented in Figures 6 and 7. The same results for the second scenario (Malaysia) are presented in Figures 8 and 9.



Summary of Fit

RSquare	0.883089
RSquare Adj	0.871708
Root Mean Square Error	0.080531
Mean of Response	0.518064
Observations (or Sum Wgts)	125

Figure 6: Scenario 1 Regression Analysis

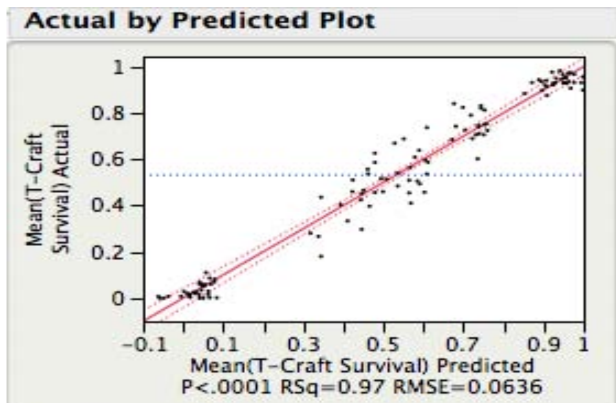
Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
ReturnToSeabase?	0.2808245	0.014457	19.42	<.0001*
(ReturnToSeabase?-0.504)*(Escorts?-0.504)	-0.488308	0.028919	-16.89	<.0001*
NumTCraft	0.0311393	0.003946	7.89	<.0001*
TCraftArmed	0.0729138	0.014445	5.05	<.0001*
(TCraftArmed-0.504)*(Escorts?-0.504)	-0.130847	0.02887	-4.53	<.0001*
Escorts?	0.0598542	0.014424	4.15	<.0001*
(TCraftArmed-0.504)*(ReturnToSeabase?-0.504)	-0.105513	0.028953	-3.64	0.0004*
(NumTCraft-8.016)*(Escorts?-0.504)	0.0272582	0.007923	3.44	0.0008*
Speed	-0.003469	0.00122	-2.84	0.0053*
(ReturnToSeabase?-0.504)*(Speed-45.032)	-0.0061	0.002439	-2.50	0.0138*
(NumTCraft-8.016)*(TCraftArmed-0.504)	0.0146238	0.007923	1.85	0.0675

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.2165879	0.06583	3.29	0.0013*
NumTCraft	0.0311393	0.003946	7.89	<.0001*
TCraftArmed	0.0729138	0.014445	5.05	<.0001*
ReturnToSeabase?	0.2808245	0.014457	19.42	<.0001*
Escorts?	0.0598542	0.014424	4.15	<.0001*
Speed	-0.003469	0.00122	-2.84	0.0053*
(NumTCraft-8.016)*(TCraftArmed-0.504)	0.0146238	0.007923	1.85	0.0675
(TCraftArmed-0.504)*(ReturnToSeabase?-0.504)	-0.105513	0.028953	-3.64	0.0004*
(NumTCraft-8.016)*(Escorts?-0.504)	0.0272582	0.007923	3.44	0.0008*
(TCraftArmed-0.504)*(Escorts?-0.504)	-0.130847	0.02887	-4.53	<.0001*
(ReturnToSeabase?-0.504)*(Escorts?-0.504)	-0.488308	0.028919	-16.89	<.0001*
(ReturnToSeabase?-0.504)*(Speed-45.032)	-0.0061	0.002439	-2.50	0.0138*

Figure 7: Scenario 1 Partition Plots



Summary of Fit

RSquare	0.969377
RSquare Adj	0.966691
Root Mean Square Error	0.06362
Mean of Response	0.531346
Observations (or Sum Wgts)	125

Figure 8: Scenario 2 Regression Analysis

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Escorts?	0.5548815	0.011396	48.69	<.0001*
TCraftArmed	0.3423607	0.011411	30.00	<.0001*
(TCraftArmed-0.504)*(Escorts?-0.504)	-0.195573	0.023202	-8.43	<.0001*
NumTCraft	0.0154272	0.003115	4.95	<.0001*
(Escorts?-0.504)*(Speed-45.032)	0.007953	0.001957	4.06	<.0001*
(NumTCraft-8.016)*(TCraftArmed-0.504)	0.0231419	0.006287	3.68	0.0004*
Speed	0.0033649	0.000961	3.50	0.0007*
(Speed-45.032)*(Speed-45.032)	-0.000685	0.000197	-3.47	0.0007*
(TCraftArmed-0.504)*(Speed-45.032)	-0.006015	0.002007	-3.00	0.0034*
(NumTCraft-8.016)*(Escorts?-0.504)	-0.016514	0.006315	-2.62	0.0101*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.169821	0.051538	-3.30	0.0013*
NumTCraft	0.0154272	0.003115	4.95	<.0001*
TCraftArmed	0.3423607	0.011411	30.00	<.0001*
Escorts?	0.5548815	0.011396	48.69	<.0001*
Speed	0.0033649	0.000961	3.50	0.0007*
(NumTCraft-8.016)*(TCraftArmed-0.504)	0.0231419	0.006287	3.68	0.0004*
(NumTCraft-8.016)*(Escorts?-0.504)	-0.016514	0.006315	-2.62	0.0101*
(TCraftArmed-0.504)*(Escorts?-0.504)	-0.195573	0.023202	-8.43	<.0001*
(TCraftArmed-0.504)*(Speed-45.032)	-0.006015	0.002007	-3.00	0.0034*
(Escorts?-0.504)*(Speed-45.032)	0.007953	0.001957	4.06	<.0001*
(Speed-45.032)*(Speed-45.032)	-0.000685	0.000197	-3.47	0.0007*

Figure 9: Scenario 2 Partition Plots

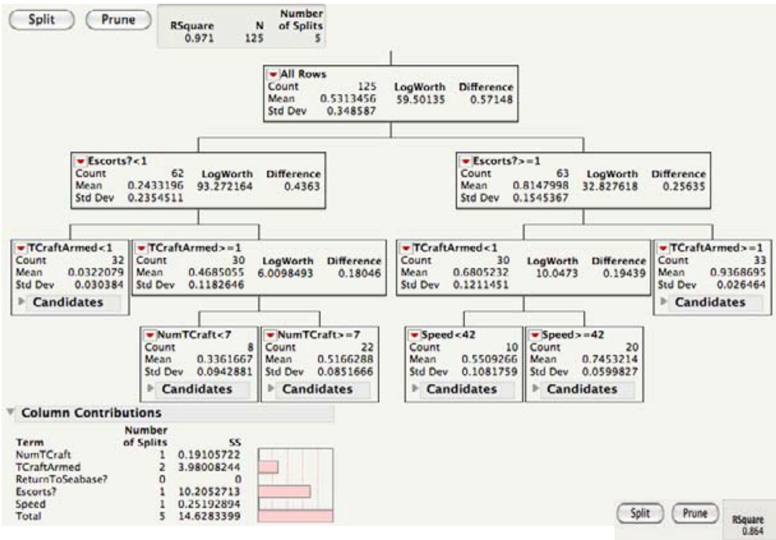


Figure 11: Scenario 2 Analysis of Distribution

The data demonstrates that, for the short range scenario, the TTP return to seabase when enemy are present appeared to be significant with respect to the T-Craft survival rate. This factor is followed by escorts and speed. In the Malaysia scenario, escort and armed appeared to be significant (in that order). Further, speed appeared to have an effect on T-Craft survivability. The distributions were analyzed to confirm the conclusions. Figure 10 presents the Columbia scenario and Figure 11 presents the Malaysia scenario.

The data presented in the analysis of distribution diagrams confirms the previous conclusions.

MODEL 2 CONCLUSIONS

The IDFW allowed for the refinement of the scenarios in MANA. The analysis of the model demonstrated that escorts and arming the T-Craft appear to be significant factors. Potential future work should include expanding the model to accommodate future design runs that vary the weapon systems on the T-Craft. This should provide insight into what escort and weapon mix is optimum for T-Craft survivability. Further expansion should also include more layers of the threat and friendly posture. Counter measures and radar jamming equipment could also be added to the T-Craft to see how that affects survivability.

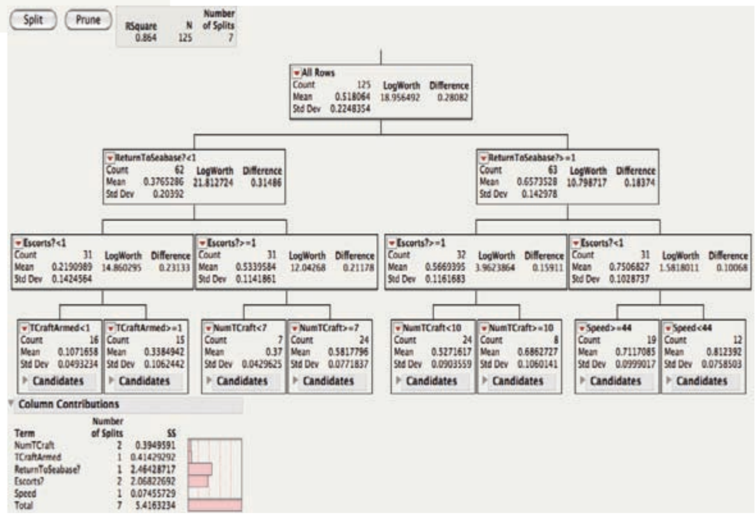


Figure 10: Scenario 1 Analysis of Distribution